WP4. IMPROVE USE EFFICIENCY OF NON-CONVENTIONAL WATER IN AGRICULTURE

Output 4.2 Living Labs equipped with TWW Irrigation trains adapted to local contexts

A 4.2.1 Design, equipment and operationalization of the demo sites. Beit Dajan, occupied Palestine

Responsible partner: WE WORLD

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ABBREVIATIONS AND ACRONYMS

Acronym	Description
DI	Drip Irrigation
Φ	Diameter
WUA	Water Users' Association
LL	Living Lab
MoA	Ministry of Agriculture
SDI	Surface Drip Irrigation System
SIM	Safe Irrigation Management
TWW	Treated Wastewater
VC	Village Council
WP	Work Package
WWTP	Wastewater Treatment plant

1. BACKGROUND

This technical report has been written in the context of the MENAWARA project on *Non-conventional Water Re-use in Agriculture in Mediterranean countries.*

The joint challenges of the MENAWARA project consist in providing additional resources by recycling drainage and wastewater, rationalizing water use practices and setting operational governance models in line with national and international plans. The project is designed to enhance access to water through the treatment of wastewater to be re-used as complementary irrigation and to strengthen the capacity of governmental institutions, non-state actors operating in the sector, technicians, and farmers.

The report reports the activities carried out in the fourth Work Package (WP4) of the MENAWARA project and, in particular, is related to the **Output 4. 2 "Living Labs equipped with TWW Irrigation trains adapted to local contexts"** and **Activity 4.2.1 "Design, equipment and operationalization of the demo sites"** as described in infographic below (Figure 1).

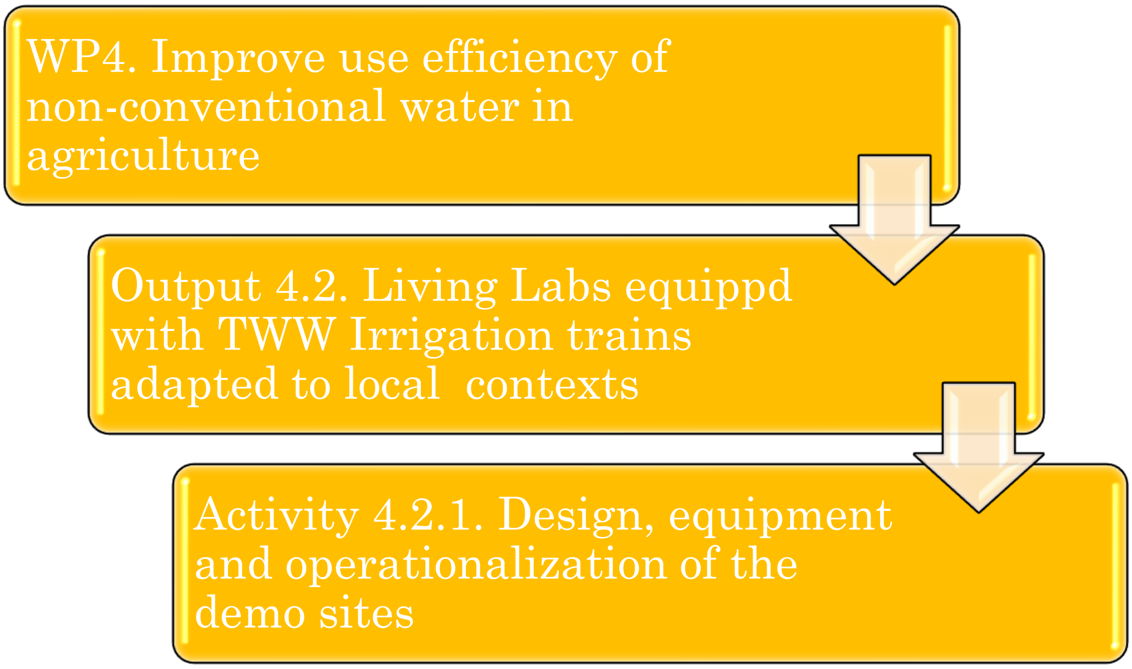

Figure 1. Infographic on the context of this technical report.

This is the second output related to the intervention in Beit Dajan, following the agronomic characterization and water and irrigation appraisal (Activity 4.1.1) whose report has been submitted on February 2020. Preliminary technical reports on the design of irrigation trains (etc…) have been drafted by CIHEAM BARI in June 2021 (Output 4.1).

More specifically the output 4.2 is described as follows: "Based on the findings of output 4.1, the irrigation trains combining technologies and techniques are identified and implemented in the intervention areas and their operative performance and their impact on water use efficiency and productivity on health and on groundwater are monitored."

This document details the technical aspects of the irrigation trains realised in Beit Dajan, occupied Palestine over the period of January 2021 to June 2022 as part of Activity 4.2.1 "Design, equipment and operationalization of the demo sites".

Before the start of the interventions on each intervention areas, several field visits and meetings have been performed to verify the technical needs to support CIHEAM BARI in elaborating the technical design for the irrigation trains to be developed in Beit Dajan. A Living Lab's implementation document has been shared by CIHEAM BARI and NRD-UNISS to support partners in jointly developing and testing innovations within a network formed of public and private stakeholders in the framework of an open innovation process.

2. Area of intervention

Beit Dajan is a Palestinian village in the Nablus Governorate in the North Central West Bank located mainly in Area B and C[1] as shown in Figure 2. The village's population is around 5000 people with 85% of households connected to the sewer network. The WWTP is located at the eastern edge of Beit Dajan village and has a daily wastewater production around 250-350 m^3 /d. The treated wastewater (TWW) is used to irrigate surrounding agricultural lands, which are mainly cultivated with olives, alfalfa or fodder, grapes and lemons.

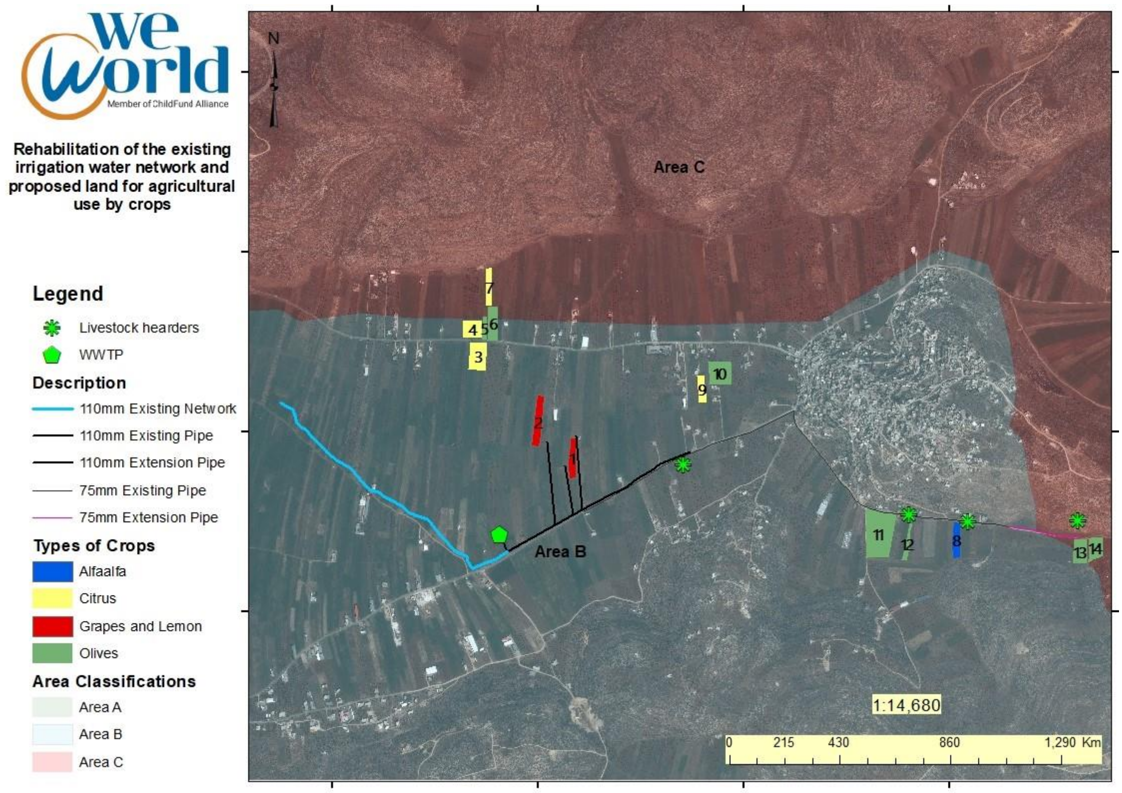

Figure 2. Map to illustrate location of Beit Dajan Village, its wastewater treatment plant (WWTP), the main pipelines of the installed irrigation network and the plots irrigated with treated wastewater (TWW).

The area of intervention for irrigation with TWW covers around 7,7 ha or 77 dunums comprises 14 plots which belong to 14 farmer members of the WUA cropped with fodder, olive, grapes and citrus trees. The crops, area and irrigation requirements for the plots irrigated with the TWW from the WWTP of Beit Dajan are shown in Table 1. The location of the plots is also visualized in Figure 2.

[1] As per the Oslo- Accords, Area C is under full control of the Israeli Occupation and includes 2/3 of the fertile agricultural land of the West Bank. Area B is under Israeli military control but under administration of the Palestinian Authority.

Table 1. Crop species, area of land, water requirement and water allocated per plot irrigated by the TWW from WWTP of Beit Dajan. Location of the plots are visualised in Figure 2.

Plot number	Crop species	Area of land plot (m²)	Yearly water requirement need* (mm/m²)	Total irrigation water allocated (mm)
1	Grape and olives	4 087	750	3065,25
2	Grape and lemon	6 082	750	4561,5
3	Lemon	7 079	750	5309,25
4	Lemon	4 979	750	3734,25
5	Olives	1 493	300	447,9
6	Olives	5 467	300	1640,1
7	Lemon	3 539	300	1061,7
8	Alfalfa	3 698	1100	4067,8
9	Lemon	3 009	750	2256,75
10	Olives	7 674	300	2302,2
11	Olives	18 006	300	5401,8
12	Olives	1 988	300	596,4
13	Olives	5 188	300	1556,4
14	Olives	4 667	300	1400,1
Total		**76 956**		37 401.4

* Calculated considering the soil characteristics, meteorological data and the crop needs. Calculation based on data from CIHEAM and MoA

By the end of the project the total area irrigated reached 106 dunums (10,6 ha.) which are 77 dunum fully equipped with irrigation trains belonging to 14 farmers who were fully engaged in the project and members of the Water User association created by the project. Irrigated land is cultivated with olive groves, vineyards, lemon trees and fodder. Further 17 dunums belonging to three of those farmers, and other 12 dunums belonging to other new farmers have been irrigated with higher quality water for a total of 106 dunums equal to 10,6 ha;

3. Design of the irrigation trains

The irrigation network in Beit Dajan Living Lab partially already existed before the MENAWARA project. Thanks to MENAWARA, 14 plots of 77 dunums and 29 dunum added are currently irrigated with the potential to be extended. The design of the irrigation network in the 14 plots belongs to the farmers members of the WUA is described here below. In Figure 3, the part of the existing network and the part that was extended (around 1 km of pipelines) is shown. In all 14 plots the irrigation system was modernized to a drip irrigation system and a subsurface irrigation system for the fodder plot (plot nr 8).

From the effluent tank on WWTP, the irrigation network ramifies into 2 branches as shown in Figure 3. The eastern branch further ramifies into 2 branches. A first branch of 326.26m (ϕ=110 mm) long serves plot 2. This pipe was extended with another pipe of ϕ=110 mm and 374.59 m long starting next to plot 2. This pipeline then bifurcates to the right into a pipe ϕ=110 of 191.75 m long in order to serve plot 8 and to the left to serve plots 3 to 7, with a pipe of ϕ=110 mm and 350.42m of length. For serving plots 9 and 10, the pipeline of ϕ=110 mm from the original plot 8 was extended for a length of around 359.45m (see Figure 3). A second parallel branch from the main branch from the WWTP, a mixage of ϕ=110 mm 299.75 m long and ϕ=110 mm serves plot 1.

The part of the network at the height of plot 1, beyond the length 277.27 m, is composed of two types of pipes: 1) with ϕ=75 mm and 1,973.72 m long; out of which around 1,631.25m serve the plots 11 and 12 planted with olive trees, and 2) ϕ=75 mm, 274.43m long serving the new plot 8 planted with fodder (see Figure 2) and plot 13 planted with olive trees and extended with 91.5m to serve plot 14 also planted with olive trees. The segments with ϕ=110 mm and ϕ=75 mm are designed longer than currently required in order to allow for a future possibility to connect additional plots to the irrigation network.

The western branch from the WWTP, already existing before MENAWARA, goes to other plots not part of the project, but they could be irrigated with TWW in case of extra production or flooding events

Each plot is equipped with a drip irrigation system including: a water flow meter and a valve to monitor both the volumes of water supply and regulate the water pressure, respectively. The water pressure variations are controlled through 27 manometers installed at the upstream and downstream of the mainline for each plot.

The plots cultivated with citrus and olive trees are equipped with a surface drip irrigation (DI) system, plot 8 cultivated with fodder is equipped with a subsurface drip irrigation (SDI) system.

The detailed drip irrigation scheme per plot can be found in Annex 1.

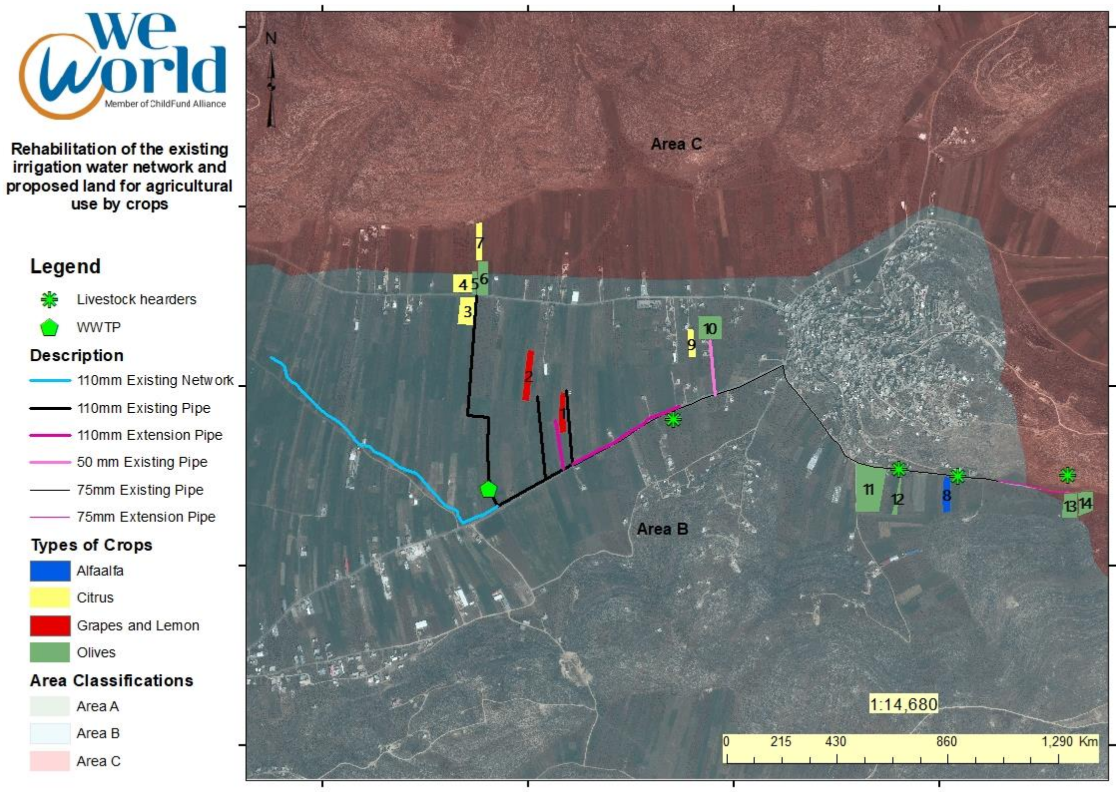

Figure 3 Map of the irrigation network designed by CIHEAM Bari connected to the WWTP of Beit Dajan illustrating the different pipelines' lengths and diameters and crop types. Plot 8 was relocated between plot 12 and13 as illustrated in Figure 2.

4. Decision Support Systems: TWW irrigation practices

Different studies were carried out in Beit Dajan to address proper TWW irrigation management, preliminary. The study was divided into two phases and developed in synergy with the Master Science in Sustainable Water and

Land Management in Agriculture at the Mediterranean Agronomic Institute of Bari within the following theses:

1) Evaluating the effects of long-term irrigation with treated wastewater on soil: A case study in Beit Dajan-Palestine;

(2) Assessment of Treated Wastewater fluxes to curb the deep percolation based on vadose zone monitoring and modelling.

Both focused on the study to retrieve the effects of TWW irrigation management by using an irrigation scheduling model system based on the soil and water data collected in 2021 (see figure 4) to both test the model and predict proper TWW irrigation plans, in order to provide the Village Council with a support to take decisions afterwards, mainly after having modernized and tested the TWW irrigation system. Once the model was calibrated, an optimal irrigation scheduling scenario assuming optimal input soil and water quality data coming from measuring of both soil and water parameters as inputs data was again run through Safe Irrigation Management -SIM - model.

Figure 4. Field campaigns carried out in 2021

SIM is a one-dimensional daily water balance model and may create irrigation scheduling options, assist with farm irrigation scheduling, and evaluate the impact of variable water quality on water balance.

SIM (figure 5) has four modules that are suitable to various meteorological, agricultural, soil, water quality, and irrigation methods situations: 1) Crop water demand and irrigation scheduling; 2) Salinity management; 3) Bacterial movement and risk assessment; 4) Nutrients' management.

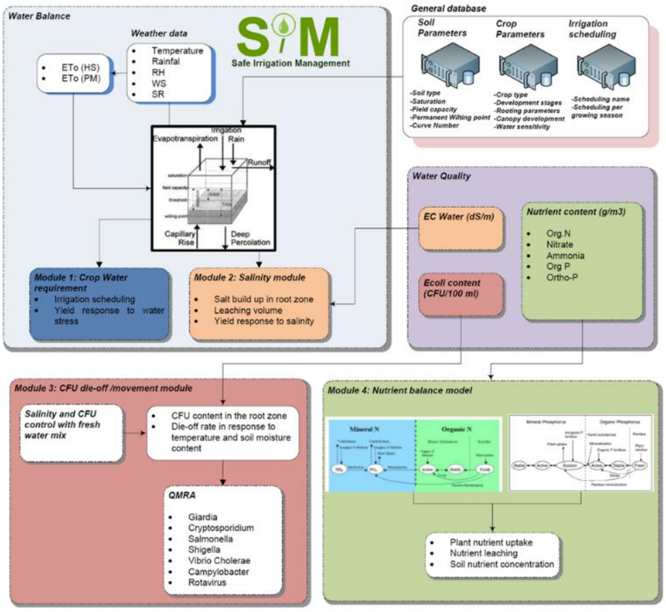

Figure 5. Flowchart of SIM model (Source: Dacchache,2020)

In detail, SIM was used to make a comparison between the farmer management (F) and the model schedule (M) scenario, this latter is based on a TWW irrigation frequency rather than on volumes with the aim to account both the water and nutrient practice with a simultaneous supply occurred by TWW.

Based on these results, it was observed the measured soil electrical conductivity, showed no salinity risk with an average. While Model performed simulation provided a combination between irrigation and fertigation strategy showing an improvement of root water uptake, and a reduction of nitrate concentrations and deep percolation fluxes.

Overall, TWW irrigation management should be designed taking into consideration both the impact of water volumes and the nutrient supplies, especially when these two surpluses cannot be separated when TWW is used as resource in agriculture.

In light of the above-mentioned results, a further methodology was tested in the third thesis “Combining Field Experiments and Modelling for a No Harm Irrigation Management with Treated Wastewater: Case Studies from Jordan and Palestine). 2) In the flow chart of figure 6 are shown the steps of the methodology.

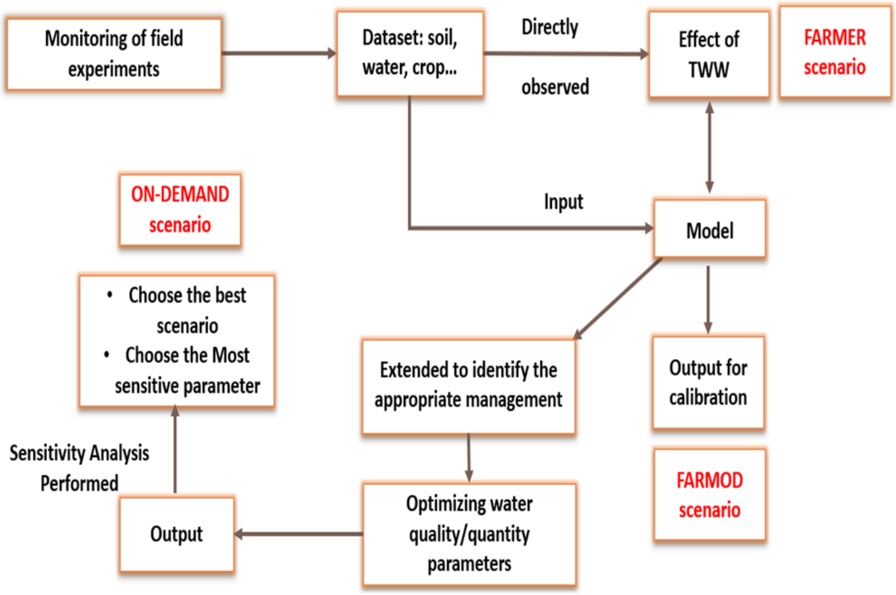

Figure 6. Methodology layout

Monitoring phase refers to data set regarding crop, water, and soil quality parameters collected in 2021 and used to rebuild FARMER scenario. That is, the effects of treated wastewater were directly observed through the farmer's experience. Likewise, the effects were also predicted by the model. In other terms, the data set collected served as input in the SIM model to perform the first run to generate the calibration of the model, called FARMOD scenario. By performing the calibration, the accuracy of the model is tested, and the same farmer behaviour is reproduced through the model.

When again the input and output of the first run are extended to identify appropriate irrigation management by optimizing water quality and quantity parameters and by running different scenarios, the best output scenario was selected, called ON-DEMAND scenario, where irrigation management was identified by selecting threshold values in the model not to exceed .Sensitivity analysis was then performed on the model output to choose the most sensitive parameters that require long-term monitoring with the aim to control the potential risks could occur overtime under TWW irrigation events.

The use of Safe Irrigation Management (SIM) model played a relevant role to select the proper irrigation schedules, and developed with an additional purpose to overcome the traditional modelling of irrigation plans that are intended for conventional water sources, that is mostly based on the evapotranspiration demand; rather accounting for water quality parameters and soil properties, balancing water requirements and deliveries and controlling water fluxes and the transport of salts in the soil and to understand a priori the complex responses.

With this regard, the obtained results demonstrate that modelling and monitoring practice aided to identifying appropriate irrigation management achieving a higher yield and lower salinity.

This methodology enabled the conservation of the soil salinity level in optimal range. These results directly correlate to the re-scaling of the frequency of irrigation events based on comparing the farmer and the model routines. They demonstrate that a robust TWW irrigation management cannot but considers the quality of water and soil and the crop nitrogen deficit.

Moreover, these results demonstrate that the use of modelling should be an integral part of the strategies that encourage the use of TWW in irrigated agriculture.

In the end, establishing a community of practice thus for an exchange of experience based on tangible results from the case studies to fulfil both individual and group goals and go a step forward. The activities carried out in this case study constitute a vital step forward in TWW reuse as it may allow for an exchange of results as per the benefit of applying those practices. That is, a series of practices that could be applied and implemented for sustainable TWW reuse as: farm training; accounting salinity, toxicity, and health hazards; selection of the irrigation methods; field management practices including soil tilth and time to withhold irrigation before harvesting. These practices could constitute an alternative strategy to schedule proper TWW irrigation.

The results of the studies were shared with stakeholders and decision makers during the roundtable held in Palestine, to feed into and to farther adopt and adjust the scheduling of the irrigation toward the actual needs of crop for water.

5. ESTABLISHMENT AND OPERATIONALIZATION OF THE LIVING LAB

Since 2019, WeWorld has been engaging with key stakeholders in Beit Dajan around the perceptions and value of treated wastewater in the municipalities with the aim of identifying and establishing a living lab (LL) for the MENAWARA project. Through MENAWARA the living lab was operationalized in Beit Dajan to design, through interactions and debates, the best solution for the water scarcity problem of the area including the design of the irrigation network of Beit Dajan. The living lab of Beit Dajan includes various stakeholders such as the 14 farmers, the Village Council of Beit Dajan, the Ministry of Agriculture (MoA), the Palestinian Water Authority, the Environmental Quality Authority, the Ministry of Local Government and the Ministry of Health, as well as the University of Al-Najah. Multiple meetings were organized (Figure 7) to discuss and share knowledge, raise awareness about the need to use TWW, the design of the network, technical considerations, and analyses to be performed, capacity building needs, governance issues and the operation and maintenance aspects.

At first, stakeholders were involved in the selection of farmers, beneficiaries of the project activities, following the below criterias:

- Residence in Beit Dajan;
- A small – Medium scale holding farmer
- good perception and willingness to use TWW
- willingness to be part of a group of users and willing to collaborate for the success of the project.

The increased acceptance to use TWW amongst farmers and the creation of the Water User Association (WUA) was a main outcome from these meetings.

Figure 7. Stakeholder meeting

The establishment of the Water Users' Association was endorsed by the stakeholders during a meeting held on the 23rd of November 2020, where governance and management of the reuse was discussed.

On December 3rd, 2020, the Water Users' Association has been created gathering 14 farmers. The meeting took place in in the venue of the village council, with the participation of the MoA, and the farmers who were going to join the Association, in addition to WE World's project team. We World presented the long-term vision of establishing the users' entity, and the benefits that would have gained in terms of reuse management, and maintenance of the irrigation systems.

The MoA supported its establishment and encouraged members to register the Association to the Ministry of Interior, to become a recognized entity from the legal point of view.

An initiated committee consisting of 3 members selected by the general assembly of farmers was created. The WUA Representative is Mr. Nasir Abu Jaish. The committee is following up the registration of the WUA, and it is entitled to follow up the O&M of the irrigation system, and to sign agreements with the Village Council. A Memorandum of Understanding (MoU) has been discussed and drafted by the Village Council and the WUA but cannot be signed yet waiting for the end of the registration process, which is still ongoing.

Throughout the project, all relevant stakeholders have been engaged in discussions and dialogue which continues to mainstreaming the reuse through the concept of LL, and strengthen User Association capacity, undertaking awareness program as well.

The Minutes of three meetings held in 2020 and 2021 can be found in Annex 3 of this report. Regular meetings were also held with the WUA, the MoA, the village council and WeWorld, key stakeholders also part of the LL to set up and formalize the WUA of Beit Dajan. In Annex 4, the 6 meetings with the WUA are detailed.

Along the project duration, multiple visits to the farmers were conducted, exchange visits with the farmers abroad as well as multiple training sessions as part of operationalizing the living lab, as described under Output 5.1 "Capacity building plan and training sessions".

Farmers' Capacity building sessions have been conducted and covered topics such as optimal water management, ownership of products grown with TWW, agricultural best practices, as well as maintenance of the irrigation system and coordination with the Village Council (VC) of Beit Dajan for optimal and inclusive governance.

These training sessions have positively impacted on the knowledge of people and has raised discussions that are crucial to strengthen the knowledge of farmers. The Beit Dajan farmers' user association and local council are developing their professional knowledge and effective WWTP management system, as well as the usage of TWW in agriculture.

Figure 8. Capacity building session

Table **2** shows an overview of the performed works made to operationalize the living lab.

Table 2. Overview of performed works to operationalize the living lab

Performed work	Description
Design of the irrigation network	After multiple meetings with the key stakeholders of the living lab of Beit Dajan, an irrigation network design was finalized by CIHEAM Bari
Rehabilitation of Beit Dajan WWTP	All the details of this intervention can be found in other reports related to output 3.4 and 3.5.

Extension of existing irrigation network	The existing network was extended with around 1 km of pipelines (see Figure 3): -699,97 m of ϕ=110 mm pipes -210 m of ϕ=75 mm pipes -91,46 m of ϕ=75 mm pipes
Installation of drip irrigation systems of 14 plots including installation of flowmeters and manometers	The details of the performed work on the plots can be found in Annex 1 and included 14 flow meters and 27 manometers to better manage and tailor the water supplied to each plot.
Provision of visual signaling	Areas where pipelines of the network are visible and accessible to the public were marked that water is not potable, pipelines used were also colored in purple according to international standards

Important for a proper functioning and the sustainability of the irrigation scheme and operationalization of the Living Lab was to identify the responsibilities of all involved stakeholders to be defined and included in the Memorandum of Understanding between Beit Dajan VC and the WUA. The responsibilities of the most important stakeholders in the operation and functioning of the TWW irrigation network are described in Table 3. While the village council is responsible for the operations and maintenance of the WWTP till the effluent tank, the farmers, through the WUA, are responsible for the distribution, operations and maintenance of the irrigation network from the effluent pump onwards. Along the project, 2 monitoring visits were conducted by the MoA and village council of Beit Dajan to ensure that the installed system complied with regulations and standards.

Other important stakeholders not mentioned in the table are the Environmental Quality Authority and the Ministry of Local Governments.

Table 3. Most important stakeholders in the Living Lab and operation of the irrigation network of Beit Dajan and their respective responsibilities. WUA: Farmer User Association; VC: Village Council.

Stakeholder	Responsibility
Water User Association (WUA)	- Managing the distribution of TWW for the farmers who have the permission from the MoA - Collecting the fees from farmers - Operation and maintenance of irrigation scheme - Have regular meetings to monitor and evaluate the sustainability of the irrigation network as well as to identify and discuss issues: • internally within the WUA • monthly meeting with VC - Regularly revise irrigation method including the water quantity and distribution - Define and monitor the number of trees that can be irrigated with TWW
Individual farmer	- Comply with regulations and the terms of license
Village Council of Beit Dajan (VC)	- Operation of WWTP - Maintenance of WWTP - Have monthly meeting with the WUA - Monitor the water quality coming out of WWTP - Definition of schedule and collection of tariffs from WUA - Request training for operators to the PWA - Information sharing with farmers and local population on TWW
Ministry of Agriculture (MoA)	- Regular inspection of products - Licensing of the WUA to reuse TWW for food production
Palestinian Water Authority (PWA)	- Training of operators of the WWTP - Develop together with the VC a water tariff system acceptable by both farmers and VC

During the meetings held with stakeholders, in order to guarantee the sustainability of all the interventions, the tariff of treated water for reuse was discussed thoroughly, and was pointed out the necessity to fix a water tariff per m3 to be paid by farmers re-using water to irrigate their plot.

At the moment, the only fee collected from Beit Dajan's householders is related to the cost of the treatment equal to 15 NIS per month per House.

The tariff per cubic meter of treated water for reuse will be introduced and included in the MoU related articles.

Before the installation and operationalization of the irrigation network, a baseline assessment of the soil quality (see results in Annex 2) was done with the support of An-Najah University and CIHEAM Bari. As per recommendation of the MoA, the endline assessment for the soil quality and health is postponed, as effects on the soil will not be noticeable after only a few months of operating the TWW irrigation system.

6. Conclusion

In conclusion, the irrigation network installed and extended in Beit Dajan in occupied Palestine can be considered a valuable intervention as based on feedback from the living lab's stakeholders. The design was not modified significantly from the original design by CIHEAM Bari (Annex 1) except for one fodder plot, plot nr 8 that was relocated as the original first farmer did not want to use TWW yet at the start of the project and was replaced with another farmer who offered his plot to cultivate fodder. The drip irrigation system with TWW is a technical solution, which could be replicated in other rural areas in Palestine where water sources are also scarce or not accessible. From the start, there was a high demand from the farmers to use the TWW and this intervention made it possible for them to tap onto this needed resource and support the farmers in Beit Dajan in increasing their productivity. Moreover, the intervention also decreased the pressure on freshwater resources which are increasingly needed for the greenhouses of Beit Dajan where vegetables are cultivated.